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MANUFACTURING CHEMICAL EQUIPMENT FROM TITANIUM

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The value of titanium as a material for the manufacturing of chemical equipment, results from its high corrosion resistance against a number of aggressive media, its high ratio of strength to density, the constancy of its mechanical characteristics in a fairly wide region of temperature. However, the high price of titanium limits the range of its usefulness, and the dimensional features of the equipment planned. Thus titanium can be used at present mainly as a material for linings, protecting the working surfaces against corrosion. Of course, this type of application involves definite technological difficulties. Besides, titanium lined equipment cannot be used with high vacua, with temperatures above 360 - 400° C or in processes where the heat transfer through the lined surface is of high importance.

Still, continuous improvements in the metallurgy of titanium and the reduction of its price, as well as the creation of titanium bi-metals, will allow the expansion of its use in the near future. At present its actual use in chemical machinery is rather limited. We know only of isolated cases where titanium has been used for the manufacture of experimental equipment, built to special order. Samples of industrial chemical apparatus are being built only by western Germany and the United States. Technically pure titanium is the most widely used form of this metal, because it is more corrosion resistant and entails less difficulty in manufacturing than its alloys. Blades and bodies of centrifugal pumps for pumping ore of various organic acids, solutions of chlorides, and of moderately concentrated hydrochloric acid are made of titanium. Such apparatus work for several years, while the alloys of the Ni-Cr-Mo type used earlier stood up for less than one year. Titanium has been used for acid-resistant injectors. The latter have been working for two years and a half with no corrosion observed, while cast iron injectors became badly corroded in less than three months. Titanium was also used in building the equipment for dyestuff production, where the purity of the final product is of greatest importance. Titanium and its alloys have been used for the manufacturing of the rotors of high speed centrifuges, where the minimizing of the rotating mass is most important.

We shall not dwell here on the question of the corrosion resistance of titanium. This matter has been reported earlier (in articles [1] - [6]). We shall mention only that the number of aggressive media that do not corrode titanium, exceeds that of those that do. Still, titanium will not stand up in dry chlorine, in molten zinc, or aluminum.. It does not withstand the action of hydro-fluoric acid, concentrated hydrochloric, sulfuric and orthophosphoric, oxalic, trichlor- and tri-flour- acetic acids, and of boiling solutions of formic and citric acids. Nor does it withstand solutions of aluminum chloride, of fluorides, and of some other substances.

At present the production of titanium and of some of its alloys has been mastered. Technically pure titanium (VT-1) contains small amounts of oxygen, hydrogen, nitrogen, carbon, silicon, and iron (see table 1). Its alloys (VT-s, VT-4, OT-4 and others) are formed by adding various elements to VT-1. Table 2 seems to indicate that VT-1 and OT-4 will prove to be the most suitable for the manufacture of chemical equipment.

At present the production of titanium stock shapes has been mastered. Sheet titanium can be had with a thickness of 0.5 to 10 mm. 400 - 1000 mm. wide and 2000 mm long. Thicker sheets (12-30 mm) can be had to special order. Seamless tubing are drawn from alloys VT-1 and VT-5. Their length varies between two and seven m, the diameters: OD - 8 to 62 mm, ID - 6 - 54 mm. Production of electro-welded tubings is being organized. In certain cases these might be economically advantageous.

Metal working industries can provide the chemical industries with titanium forgings, rolled profiles, and wire - the latter for welding purposes in particular. Wires of very small calibers (0.01 mm) are being produced and can be used for corrosion resisting sieves.

Machinability of technical titanium is nearly the same as that of stainless steel. Its alloys are, however, much less machinable. This pertains especially to finishing operations (expanding, drawing, grinding, polishing). The causes are: dulling of the tools by particles of titanium carbide; attrition of titanium chips to the cutting edge, and rapid cold-hardening.

Effects of attrition and cold work can be reduced by using finely sharpened cutting tools, and by arranging for automatic feed, which eliminates the cutter's gliding along the surface of the machined piece. This minimizes cold hardening and adhesion. General requisites are: extreme rigidity of the attachments of both the tool and work; absence of vibrations and obligatory use of cooling.

The cutting of titanium is rather tricky, especially with larger pieces. Various strongly cooled mechanical saws work satisfactorily. Some foreign shops prefer the use of water-proof abrasive wheels. Good results are obtained also by using rapidly vibrating wheels. They cut stock 160 mm in diameter in about ten minutes. Good results were obtained in USSR by using guillotine and roller type shears.

For cutting titanium and its alloys a tool rigged with hard alloys VK-4 and VK-8 is being used. The following shape of the cutting edge is preferable: frontal angle 0°, rear angle 12°, main angle in the 45° plane; auxiliary in the 12° plane; elevation angle of the edge 0°; top radius 0.8 mm. Shavings should be as thick as possible, because thin chips are apt to catch fire. Cutting must be done under an intense cooling using the five percent emulsion.

Some foreign shops increase the life of the cutting tool by injecting liquid carbon dioxide into the zone of contact between the tool and the work. Pressure of the CO_2 jet is about 54 kg/cm sq. The carbon dioxide forms a film on the surface layer of the machined piece with a temperature time of - 79°C.

The schedules of lathe cutting are given in table 3.

There are practically no literature data on the working of titanium by planing. According to the information available, planing cutters are armed by tips of hard alloy VK-5. Their shape: frontal angle: 5°; rear angle 10°; run of cutting same as for 18.8 steel. Depth of cutting - not greater than 5 - 6 mm.

Titanium milling is frequently accompanied by the adhesion of chips to the tools. This can be averted by intersifying the dissipation of heat. Usually the velocity of the miller is small, the chips are wide and thick; the feeding velocity high. The chip adhesion is less when the tool and the work move in the same direction. It is desirable to use liquids which produce a lubricating effect and not a cooling one. Experience shows that the tool's file increases when the lubricating oil contains a lot of sulfur. Aqueous solutions and emulsions are not recommended. Milling schedules: cutter's velocity 28-158 meter per minute; load per tooth - 0.03 - 0.08 mm; depth of cutting 1.25 - 4 mm. Tooth's shape: frontal angle 0°; rear angle 18°; angle in the plane 60°; auxiliary angle 30°; angle of elevation 15°; transition facet - 0.61.00 mm.

Titanium drilling takes place at low speed and strong feeding; neither stop-overs nor hand feeding can be allowed. Such conditions greatly reduce the extent of cold hardening. Either high speed steel drill or carbide tipped ordinary drill bits can be used. As a rule, the first are being used when the depth of the hole being drilled is no greater than 1.5 times the diameter. For higher rigidity the drill should have a short channel and a powerful core. The leading strips of the drills are ground off, because anything protruding from the surface tears titanium and causes the chip to fold over. The arch at the drill's tip is grounded off to its very center; this cuts down the axial component of the pressure and eliminates the squeezing out of the metal from the center of the hole. The edges of the drill are provided with channels in order to break up the chips and improve their elimination. Drills armed with carbide tips are given the following shape: frontal angle y 0°, rear angle α = 12°, angle at the drill's tip $2\gamma = 140^\circ$. For high speed drills the frontal and rear angles only are changed ($\gamma = 3$ to 5°; $\alpha = 12 - 14^\circ$). Cutting speeds: for carbide tipped drills 10 - 15 mm in diameter. Work is conducted under ample cooling by 5 percent emulsion.

Threading of titanium pieces, involves no particular difficulties. It is done with a cutting speed of 15-25 m/min, the cutter having the following shape: frontal angle $\gamma = -5^\circ$, rear angle $\alpha = 12^\circ$. Using a tap internally is much more intricate. The taps usually have their teeth in a chess-guard order. Cutting speed 1-2 m/min. and the work has to be lubricated by a mixture of sulfofrezon and oleinic acid.

Titanium dust is explosive, therefore only wet grinding is being used. The cooling is done either by a ten percent solution of sodium nitrite, or by three percent sodium solution. Grinding wheels of green carborundum, grain size 80, hardness CM_1 - CM_2 are being used. The usual velocity of the wheel is 25 - 30 m/sec, work's rotation speed - 10 - 12 m/sec, grinding depth = 0.02 mm per double run, longitudinal feed 0.2 - 0.3 V mm per turn of the work, where V is the width of the wheel. Surface finess after grinding $\nabla\nabla\nabla 7$.

Polishing of titanium articles is done by bands of linen impregnated with an abrasive of grain-size 100-200. Same cooling liquids are used. Surface finish after polishing = $\nabla\nabla\nabla 8$ to $\nabla\nabla\nabla\nabla 9$.

Die-stamping. Titanium stamping is far more difficult that that of stainless steel. Its flow into dies proceeds differently from that of the steel and therefore special dies must be used. Its resistance to deformation is greater than that of the steel and therefore the pressure required is about 25 percent higher. The die must be more massive and all transitional radii must be larger.

By forging and die-stamping rods, rings, disks, flanges, valves and other articles can be made of titanium. The temperature conditions are selected in accordance with the diagrams of technological ductility. In every concrete case the selection of temperature depends upon the shape and size of the article to be produced. For best results, the reductions per stage must be moderate; forging is done by light but frequent strokes.

Free forging temperature of titanium and its alloys are between 750° and $1100^\circ C$, while die-stamping calls for temperatures about $50^\circ C$ lower. The dies are preheated to about $250^\circ C$ at the start. Usually the stock-heating takes place in electric, gas or oil furnaces, with a slightly oxydizing atmosphere, although it is better to use furnaces with an inert atmosphere. For the hot pressing of titanium alloys it is preferable to use an equipment where the pistons move rather slowly, hydraulic, crank and similar presses.

Technical titanium can be cold worked by drawing, bending, and analogous operations. Titanium's ductility is comparable to that of cold rolled 18:8 stainless steel, titanium alloys being much less ductile. Due to titanium's tendency to rapid cold hardening, shaping must proceed with frequent anneals. The finished product has also to be annealed to eliminate strains and prevent cracking. Cold working of titanium calls for pressures much greater than those needed for carbon steels. The shaping of parts from sheet titanium can be done in tool dies, in bending presses, and in three-roll mills. The permissible radii of the bends must run 1.5 to 5 times the thickness of the sheet, depending on the material being deformed. Bending work must take into account the titanium's resilience which is about the same as in 18:8 stainless steel.

Drawing capacity of titanium is somewhat lower than stainless steel. However, we are informed that any part that can be deep drawn to shape in carbon steel, can be deep drawn from technically pure titanium as well. In the USA, deep drawing to 40 percent has been obtained in some processes. In the USSR the limit of cold drawing of titanium VT-1 is considered to be 0.30 (after preheating). Drawing of titanium is being done at modest speeds (maximum 0.25 m/sec) and frequent anneals; special lubricants are used to avoid tearing and folding over, and the dies must be frequently polished.

Pressing operations are performed by steel pressing tools in both states -- cold and preheated to 500 - 700°C.

Titanium tubings can be bent on tube-bending stands with the use of forming dies. Radii of bending are the same as those for tubes of stainless steel. Best results are secured with tubes of over 12 mm in diam. Bending of smaller tubes frequently ends in local cracking. Titanium tubes can be expanded without preheating, but the degree of spreading must not exceed 35 percent. A somewhat larger expansion can be obtained with the preheating to 200 - 320°C.

Welding. Molten titanium combines intensity with oxygen and nitrogen, therefore its arc welding must be performed in the atmosphere of argon or helium and sometimes of their mixture. Gas welding can yield quality results only when the protection by the inert atmosphere completely covers a rather wide adjoining zone of thermic effects besides the zone of melting. Various tuyeres and moving hoods (semi-chamgers) are used for this kind of work. Arc welding in argon, using a non-melting tungsten electrode with argon of the composition (1) prescribed by the specification TU-NKhP 4315-54, permits to pruduce seams in titanium pieces at any position of the work being welded. Direct current is used in welding. Surfaces to be welded must be cleaned of scale and dirt by sand-blowing, followed by etching in sodium hydroxide solution or by a brief immersion into a mixture of nitric and hydrofluoric acids. The inner surface of the seam must be particularly well protected. This is done either by using copper inserts, tightly fitted to the inner surfaces, or by blowing in protective gas through special nozzles. Sometimes the welding is done in special gas-tight chambers filled with inert gas. This insures the highest quality in the welded joints.

However, quite satisfactory results can be obtained by using automatically moving hoods (semi-chambers) and automatically moving welding tips. In order to raise the stability of the welding arc and to eliminate the rowing of the arc which causes the lack of uniformity in the seans' cross-section, tungsten electrodes containing thorium oxide are recommended (mark VT-15). The top of the electrode is usually ground to the shape of a cone 3 - 6 times as long as the rod's diameter.

Besides welding with a non-melting tungsten electrode, the use of a melting electrode of titanium wire also leads to acceptable results in argon arc welding. However this manner of welding has not yet met with industrial acceptance.

The schedules of argon-arc welding are shown in table 4 [4, 6].

Paton's Institute of electric welding worked out a method of titanium welding under a layer of an oxygen-free flux. Spot and seam welding present no difficulties.

In this case the corrosion resistance in the seam and in the adjoining areas does not differ much from that of the article being welded. Seam ductility is somewhat lower, but remains good, amounting to a minimum of 20 percent in elongation. Satisfactory values of strength and ductility are obtained without the use of a protecting atmosphere, but the quality falls behind that obtained under a full protection in gas-tight chambers. In the latter case the strength of seams proves to be equal to that of the base metal. Additional annealing does not result in any noticeable improvement of the welded joints executed in alloys VT-1, VT-4, VT-5, OT-4. It does, however, eliminate internal stresses. Annealing is executed for 30 - 45 min. at 600 - 700°C. A local annealing with the use of a gas burner, immediately after completing the welding with the article still in position, is permissible.

We shall conclude by stating that in spite of the high price of titanium, its use for chemical construction is economically justifiable whenever stainless steels and plastics are found to be insufficiently corrosion-resisting.

Metallurgical industries are already producing a number of stock shapes for the use of the chemical equipment industries, and these lists will grow with the growth of the demand for titanium.

Technological features of titanium-weldability, machinability, pressure shaping - do not materially differ from those of other materials that are already largely used in chemical industries. Consequently the application of titanium for the manufacturing of chemical equipment will not encounter any particular difficulties.

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Table 1

Chemical composition of Titanium and its alloys in percent

Trade-mark	Ti	Mn	Mo	Cr	Al	V	Maxima % of impurities and slight additions					
							C	Fe	Si	O_2	N_2	H_2
BT1	Base	—	—	—		—	0,05	0,3	0,15	0,15	0,04	0,015
BT3	»	—	—	2—3,0	4—5,2	—	0,1	0,3	0,2	0,2	0,05	0,015
BT3-1	»	—	1—2,0	1,5—2,5	4—5,2	—	0,1	0,5	0,2	0,2	0,05	0,015
BT4	»	1—2,0	—	—	4—5,0	—	0,05	0,3	0,15	0,15	0,05	0,015
OT4	»	1—2,0	—	—	2—3,5	—	0,1	0,4	0,15	0,15	0,05	0,015
BT5	»	—	—	—	4—5,5	—	0,05	0,3	0,15	0,15	0,04	0,015
BT6	»	—	—	—	5—6,5	3,5—4,5	0,05	0,3	0,15	0,15	0,04	0,015
BT8	»	—	2,8—3,8	—	5,8—6,8	—	0,1	0,4	0,2	0,2	0,05	0,01

Table 2

Physical characteristics of titanium and of its alloy

Feature	Trade mark							
	BT1	BT3	BT3-1	BT4	OT4	BT5	BT6	BT8
Ultimate strength kg/mm.sq.	45—60	95—115	95—120	80—90	70—90	80—95	90—100	100—110
Yield point kg/mm.sq.	38—50	85—105	85—110	70—80	55—65	70—85	80—90	105—118
Elongation %	Не менее 25	10—16	10—16	15—22	12—20	12—25	8—13 10—15	8—12
Area reduction %	Не менее 50	25—40	25—40	20—30	25—55	30—45	30—45	30—50
Spec. wt g/cm.cube	4,5	4,46	4,5	4,6	4—55	4,5	4,43	4,46—4,48
Electric resistivity in	—	1,56	1,36	—	—	1,03	1,6	1,61
Linear expansion per degree C.	$8,2 \times 10^{-6}$	$8,4 \times 10^{-6}$	$8,6 \times 10^{-6}$	$8,5 \times 10^{-6}$	8×10^{-6}	8×10^{-6}	$8,41 \times 10^{-6}$	$8,4 \times 10^{-6}$
Heat conductivity cal/cm.sec.	0,039	0,017	0,019	0,02—0,03	0,02	0,18	0,18	0,017

Note; Titanium and its alloys are non-magnetic

Table 3

Schedule of cutting operations for titanium (in the lathe)

Feed mm/turn	Speed of cutting meter-min. for a depth of 1 mm.			
	1	2	3	4
0,03	53,8	51,6	50,5	49,5
0,1	50	48	46,7	46
0,15	44,2	42	41,2	40,5
0,2	40,5	39	37,5	37
0,25	38	36,5	35,6	35
0,3	36	34,4	33,5	33
0,35	34,2	32,8	32	31,2
0,4	33,3	32	31	30,5

Table 4

Orientation schedules of titanium welding using an argon-arc and a non-fusible electrode

Sheet thickness mm.	Welding current amperes	Number of passes	Diam of the tuyere mm.	Argon delivery liter/min.
1,0	50—70	1	6—8	6—8
2,0	70—80	1	8—10	8—12
2,5	80—100	1	8—10	8—12
3,0	110—120	1—2	8—10	8—12
4,0	130—140	2	10—15	12—16
5,0	130—140	2—3	10—15	12—16
6,0	130—140	3—4	10—15	12—16
7,0	140—150	4—5	10—15	12—16

Notes: 1. Arc voltage 11-14 volt.
2. Welding speed 20-25 cm/min.

END